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The Complexity-Independence of the Origin of Life

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Models of prebiotic evolution.

The quest for a non-earth-centric definition of life.

The deep-rooted paradoxes of the Origin of Life (OL).

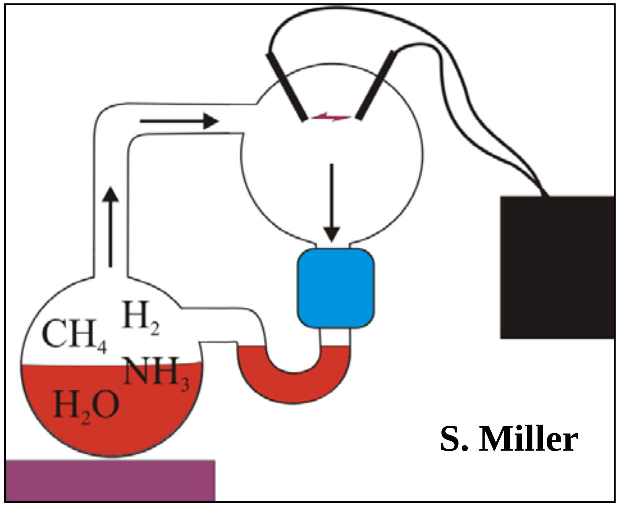
Drivers of the Origin and Evolution of Life (OEL).

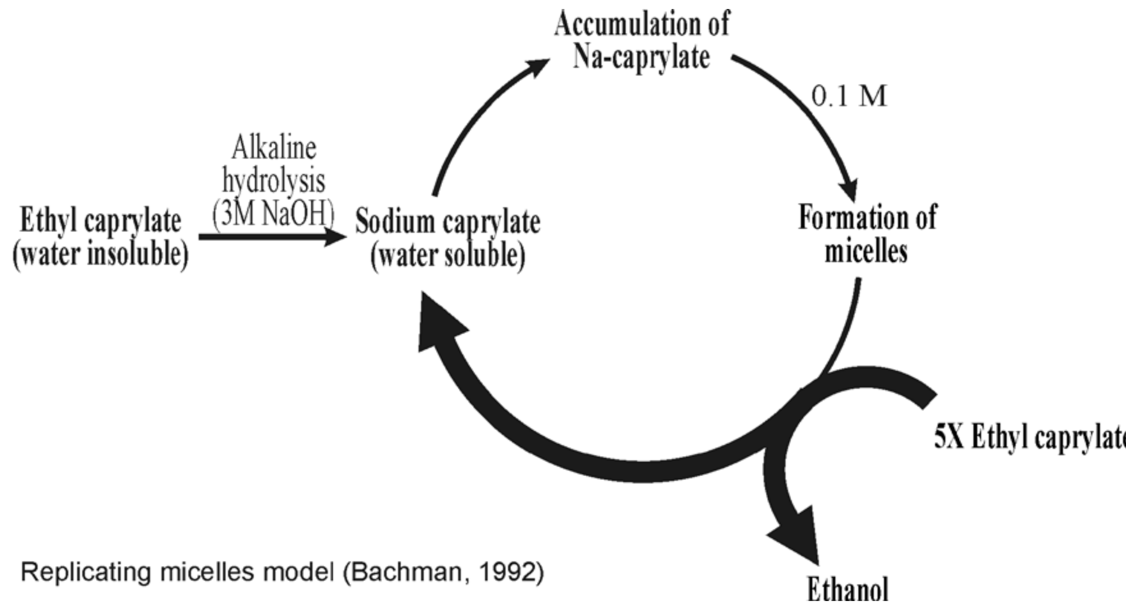
Evolution patterns of early life.

Searching for quantitative means to correlate changes in organization with changes in *Ef*.

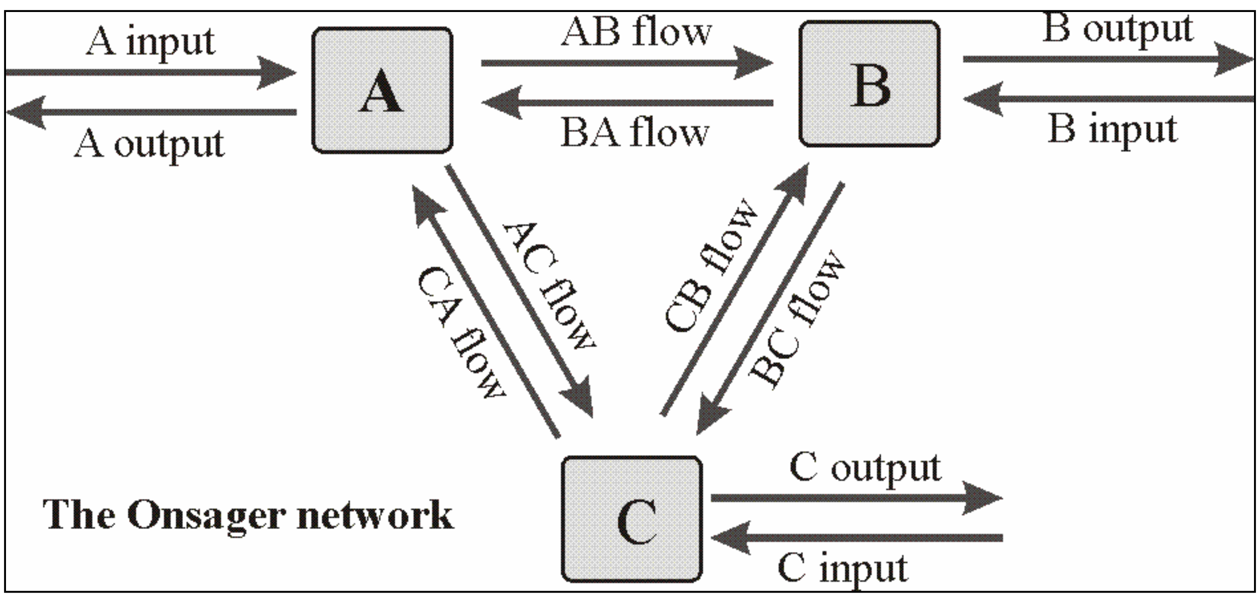
Means to simulate early life evolution:

- Chemical biomimetics
- Cybernetic biomimetics

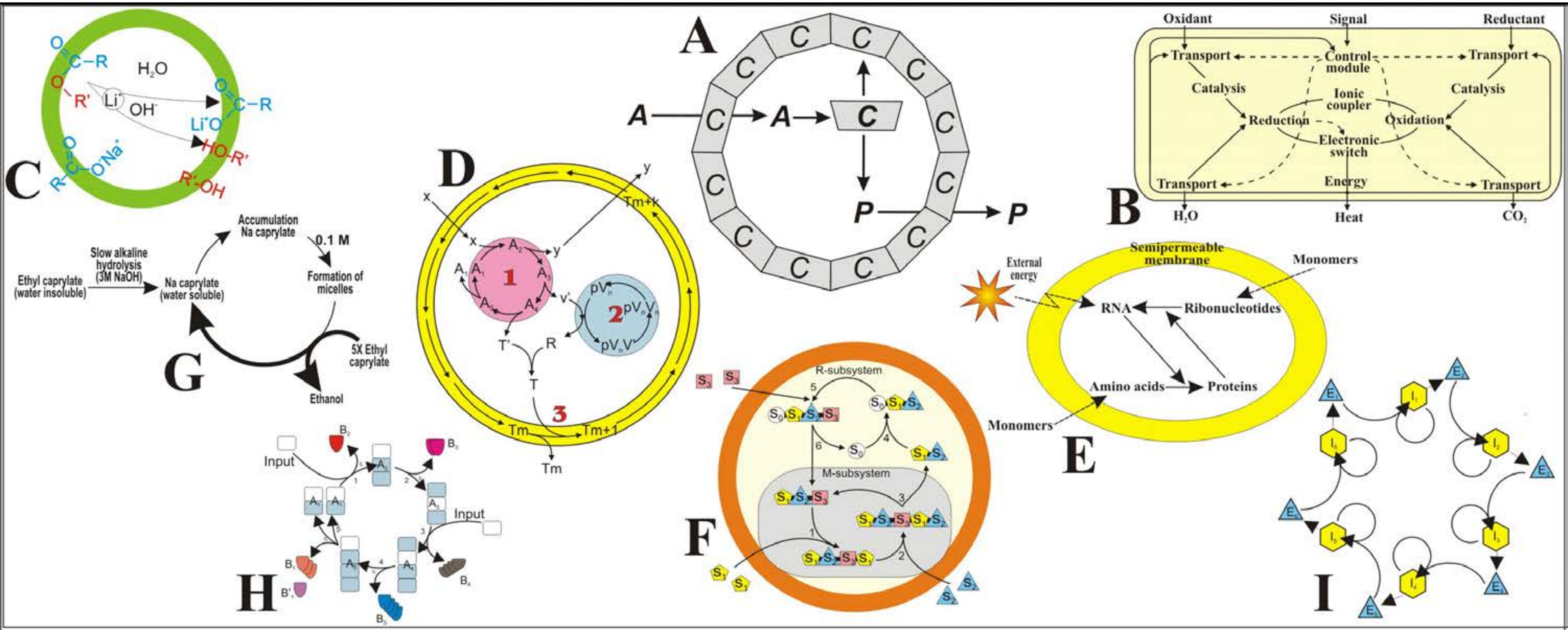




Replicating micelles model (Bachman, 1992)



The Diversity of Early Life Models



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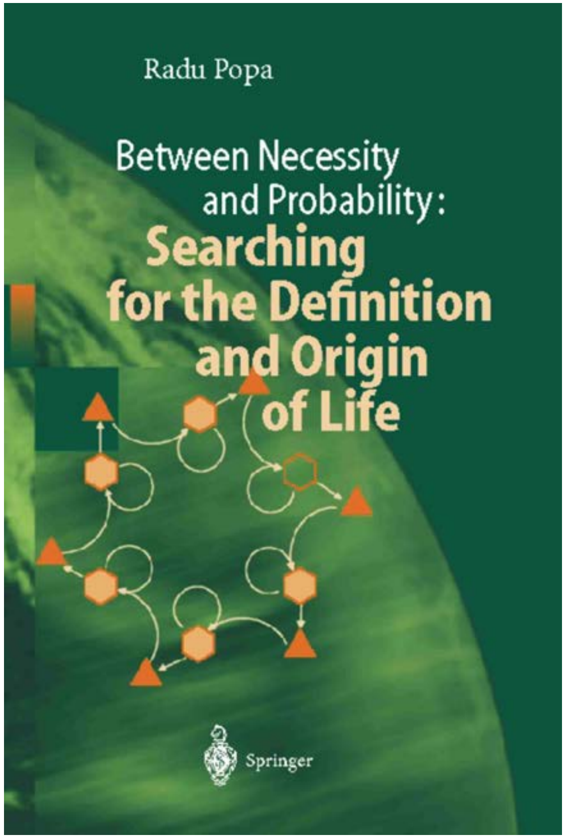
+ M. Bedau, Tierra (T. Ray), Avida (C. Adami), eVita, Evolve, DarwinBots; Framsticks; Calresco …. and more.

The Quest for a Non-earth-centric Definition of Life

A true life definition must exclude any material references and include all forms of life, (or things that may become alive)

Biological or Non-biological
Terrestrial or Extraterrestrial
Chemical or Non-chemical
Material or Cybernetic
Natural or Artificial
Self-evolved or Assisted



Identifying material-independent features of life.

Energy flow and Entropy dissipation
Self-maintenance
Growth and Reproduction
Controlled boundaries
Changes in: Specificity, Order, Complexity, Entropy
Analogic and Digital information
Evolution

Proposing a definition for life? (Attention! - Life definition get personal)

- The attribute of being alive may occur at the individual or collective level.
- Living systems and Life are different concepts with different properties.
  Living systems are actual systems (i.e. expressed entities).
  Life is an attribute of living systems, or a theoretical concept about living systems in general.

"Living entities are homeostatic systems capable of adaptive evolution individually, collectively or as a line of descent"

"Life is what living systems collectively do, or collectively represent".

Distinguishing the living from the non-living means identifying a set of achievements along the features listed above.

Deep-rooted Paradoxes of the Origin of Life

Haldane's dilemma (1957) ***Long negentropic evolution***
A means to calculate limits for the speed of a beneficial evolution.
Assume OL in "*n*" chemical steps. For a forward probability "*p*" per one step, the odds for the n^{th} event to occur is "p^n".
Although the probability of a forward upgrade (A+B=>AB) exists, the 2^{nd} law of thermodynamics makes sure that the forward direction of OEL is less likely than the reverse (A+B<=AB).
Continuous accretion of life in numerous steps, each step with increasing complexity, is probabilistically unlikely.

Thresholds of prohibited minimal complexity (Kauffman S., 1993)
Simple chemical networks cannot contain sufficient feed-back mechanisms to cover all self-regulating contingencies.
True self-control only becomes possible at impossibly high complexity.
All simulations of OL ever made show regression; the advent of advanced cells remains hard to explain.

The genome size paradox
Genetic information is written in a 1D sequence.
It cannot control the liberties of organization and function of a chemical network (which is a 4D system).

Complex origin and forward evolution are prohibited.
Life did not self-originate.
Probability did play a role in the OL, but overall external controllers must have assisted the OEL.

Searching for a Driver for the OEL
(The Anthropic Cosmological Principle)

The weak anthropic principle (Barrow and Tipler, 1986).

The universe is build in a way that supports life based on carbon.

The universe is biophilic (suspiciously comfortable for life).

Cosmological fine-tuning (Carr and Rees, 2002; Falk, 2004).

The constants of this universe are balanced for this implementation of universe to exist.

It is the values of the cosmic constants that promote the existence of life.

Postulate: If the values for some key physical parameters would have been slightly different then galaxies, stars, planets would not exist (and life the way we know it) would not exist.

Examples of reasoning using the Anthropic principle:

The strength of gravity

A bit stronger and the universe had collapsed in a “Big Crunch” before life evolved.

A bit weaker and matter would never have coalesced into stars and planets.

The smoothness of the Big Bang

If initial fluctuations were smaller the universe would be dark and featureless.

A bit larger and the universe would be dominated by black holes, rather than stars and galaxies

The masses of subatomic particles

The neutron is just slightly heavier than the proton, ensuring the existence of hydrogen.

If protons were a little bit heavier they would not spontaneously decay into neutrons, and there would be no hydrogen and no stars.

Searching for a Driver for the OEL
(Correlating Organization With Energy Dissipation)

0^{th} law of thermodynamics. If A is in thermal equilibrium with C, and B is in thermal equilibrium with C, then A is in thermal equilibrium with B.
1^{st} law of thermodynamics. When one form of energy is converted into another, the total energy is conserved.
2^{nd} law of thermodynamics. As long as transformations occur the overall entropy increases.
3^{rd} law of thermodynamics. The entropy of a pure element or substance in a perfectly crystalline form is 0 at 0^oK.

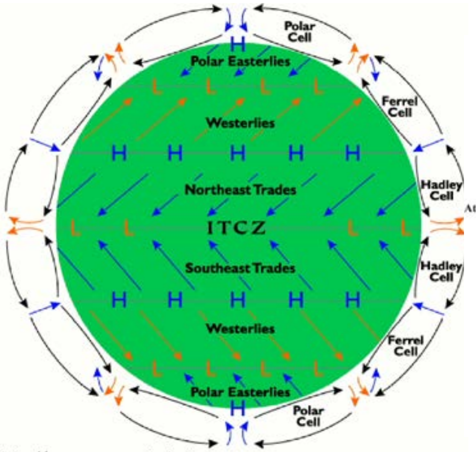
A 4^{th} law? Based on a quantitative relationship between ΔE_f and changes in Organization.
Lars Onsager's Reciprocal relations (1929-1931) showed correlation btw "Heat flow per unit of pressure difference and Density (matter) flow per unit of temperature".
Nicolis and Prigogine (1977) analyzed "Self organization in non-equilibrium systems".
Shinitziky et al. (2007); Dilip Kondepudi et al., (2008) – Connection between energy dissipation and chirality.

Changes in E flux may be coupled with changes in the randomness of organization and behavior.
If energy dissipation increases the overall entropy (e.g. heat production) then the dissipation of entropy may help decrease the local entropy (i.e. lead to non-random organization).

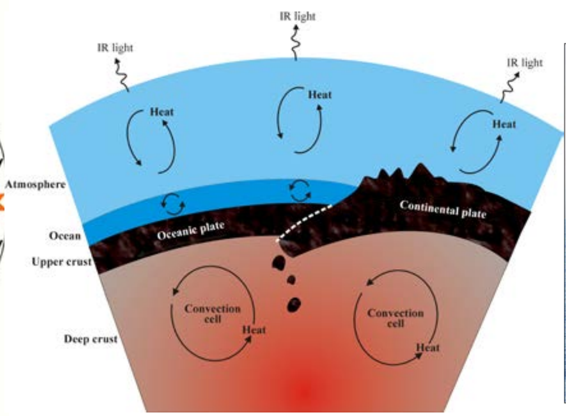
Analyzed by: Disequilibrium thermodynamics, Statistical mechanics, ALife, Climatology, Ecology, Socio-economics, Astrobiology.

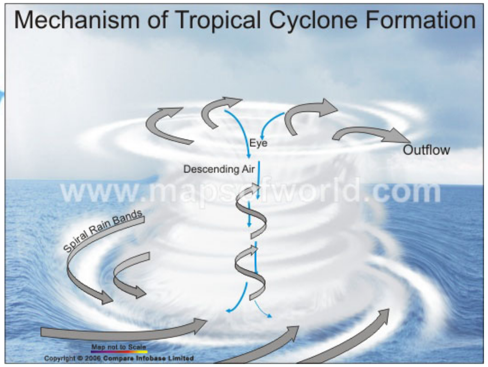
The Evolution Toward Life via ΔE_{flux}

Per Bak's 4th law (1996) – *"If the flow of energy from a source to a sink is impaired, and E flows through an intermediate system, the force of the energy gradient will tend to organize the system in a way that will increase the overall E flow"*. (examples: fire, lightning, growth of crystals, formation of valleys, sand dunes, fluid vortices, convection cells and energy dissipating storms).
A definitive theory for this "*law?*" still does not exist yet because different levels of organization have different energy, entropy and information content (*i.e*. variable and often unpredictable J/bit ratio).



http://www.newmediastudio.org
Like Schlesinger Figure 3.3 p. 52.

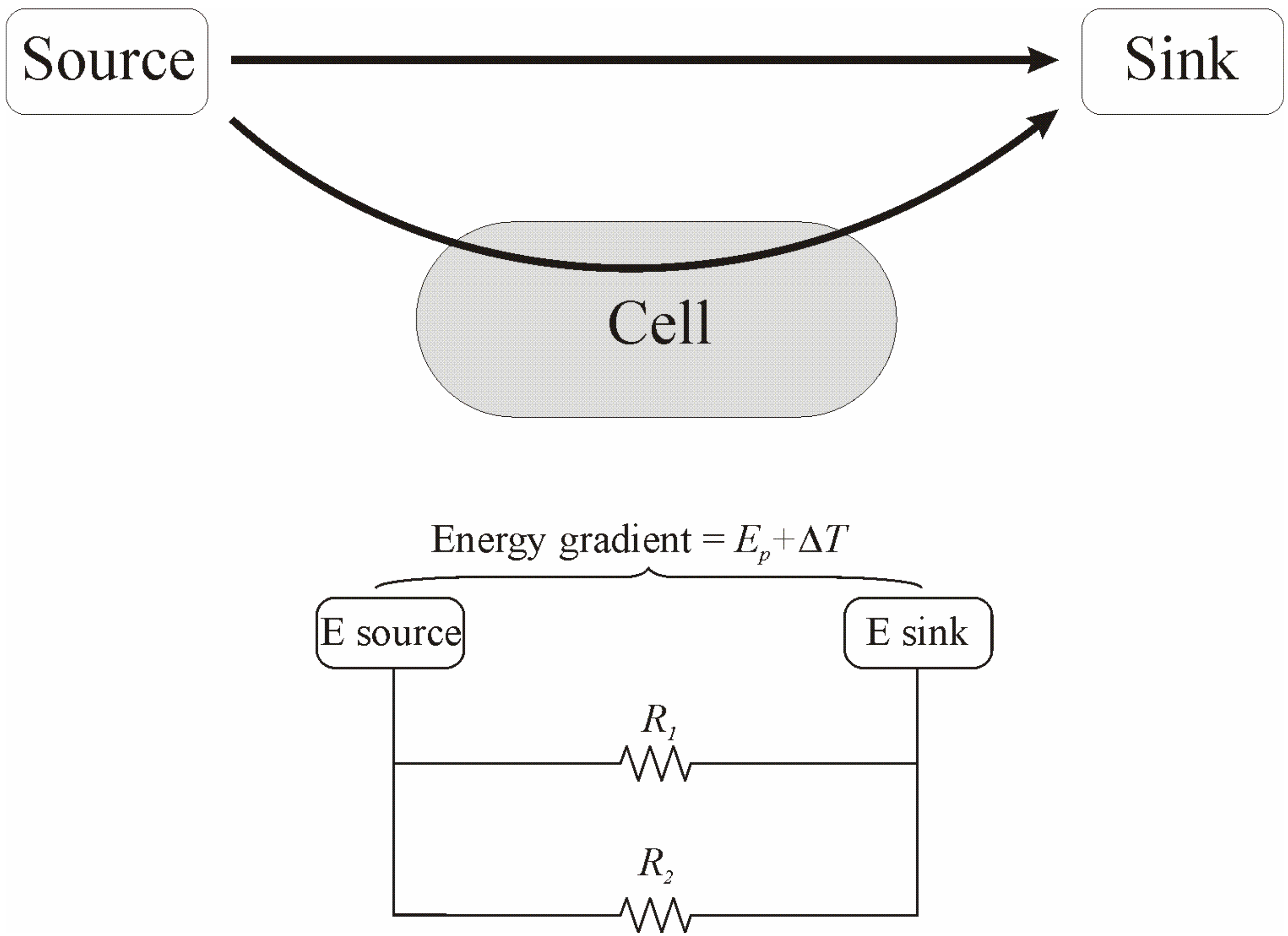




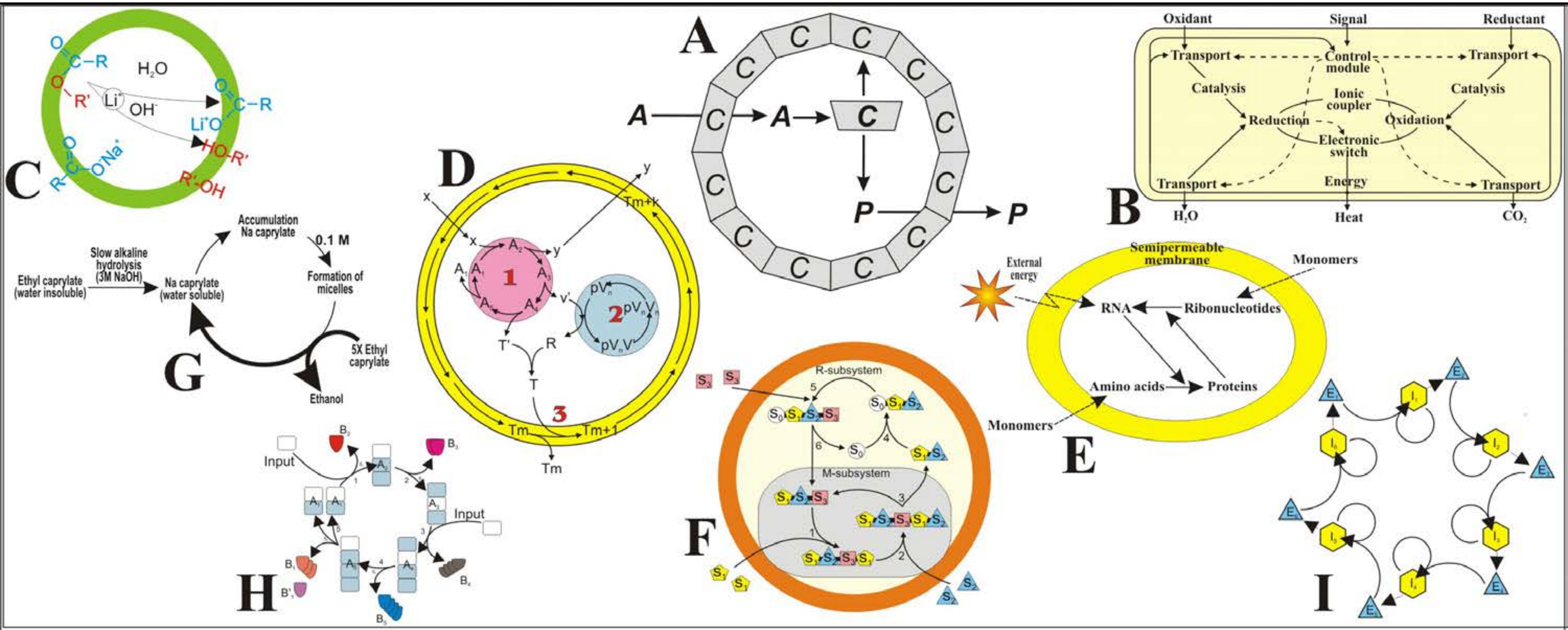
By extension - A quantitative connection will also exist between ΔE_{flux} and the OL.
The starter mechanism to implement this connection is a catalyst or positive feed back added to the system. In this case the driver for the OL can be viewed as the expansion of the universe (Eric J. Chaisson, 2002).

The 1st condition for an un-assisted OEL: *A dynamic system can evolve from being lifeless to being alive only if the overall rate of entropization (at any given point) during evolution remains smaller than the negentropic effect of the 4th law.*
The 2nd condition for an un-assisted OEL: *Because each $E_{flux}{}^{o}$ will only cover a given level of Organization costs, negentropic evolution requires ΔE_{flux}. The system state is controlled by E_{flux} while evolution toward more organization is controlled by a $+\Delta E_{flux}$.*

Living Systems as Double Circuits



Evolution Patterns of Early Life in Abstract Chemical Networks



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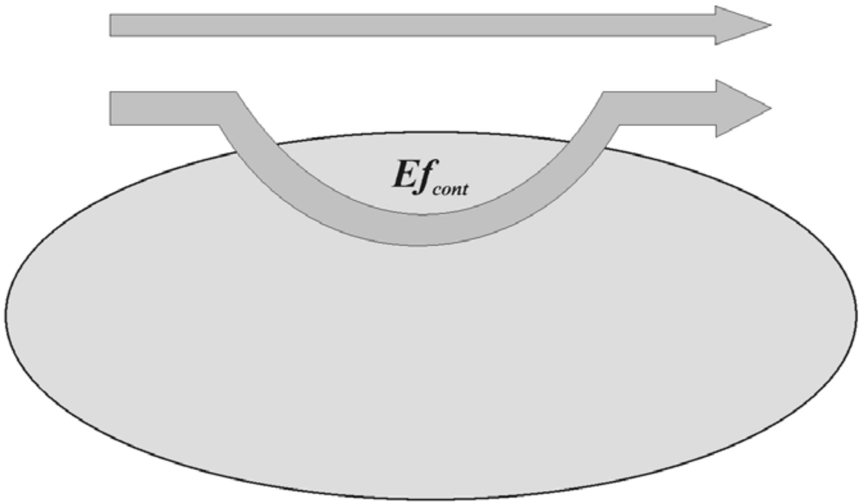
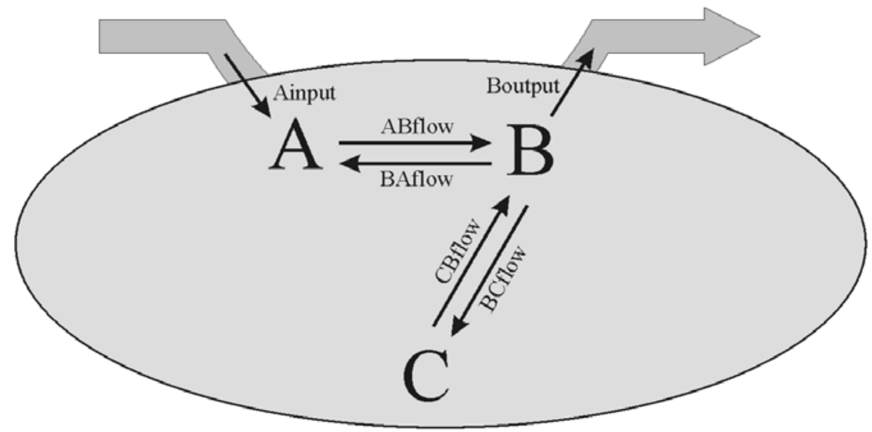
Develop chemistry-independent means to study changes in the "*Organization*" of components and *Ef* in abstract networks.

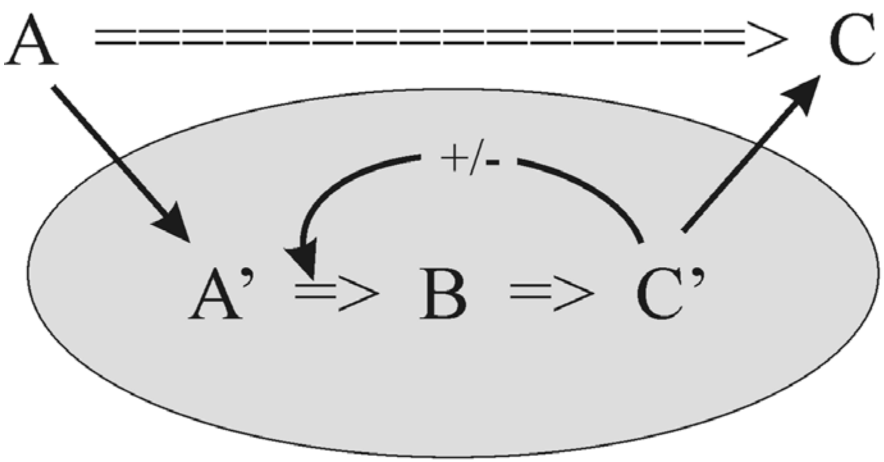
Evolution of Organization in Abstract Networks



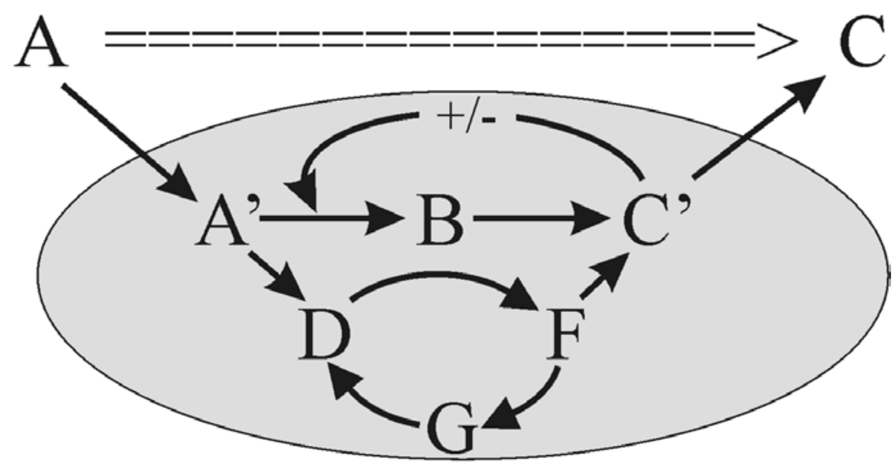
Energy flow contribution



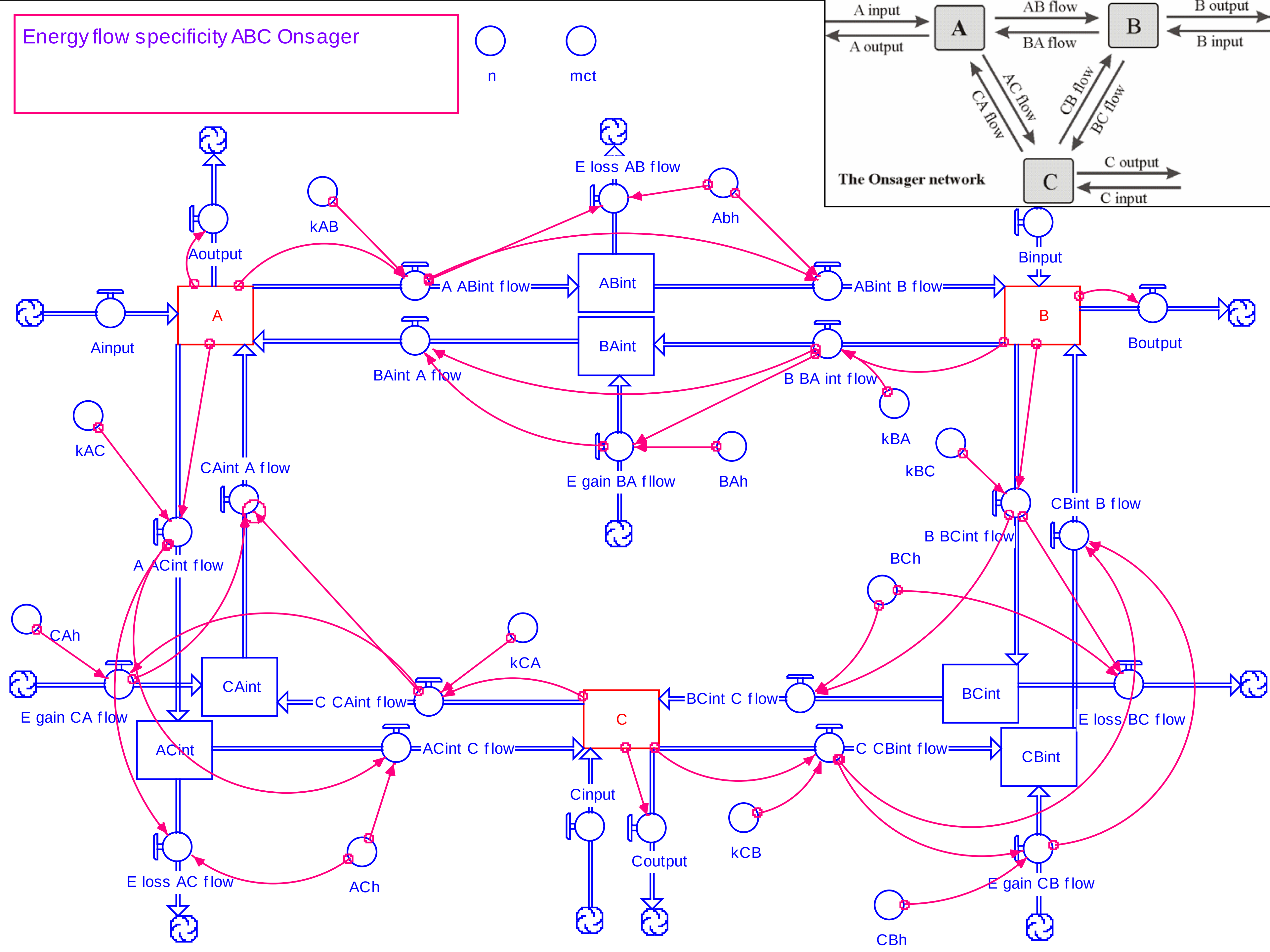
Energy reserves



Feed back regulation

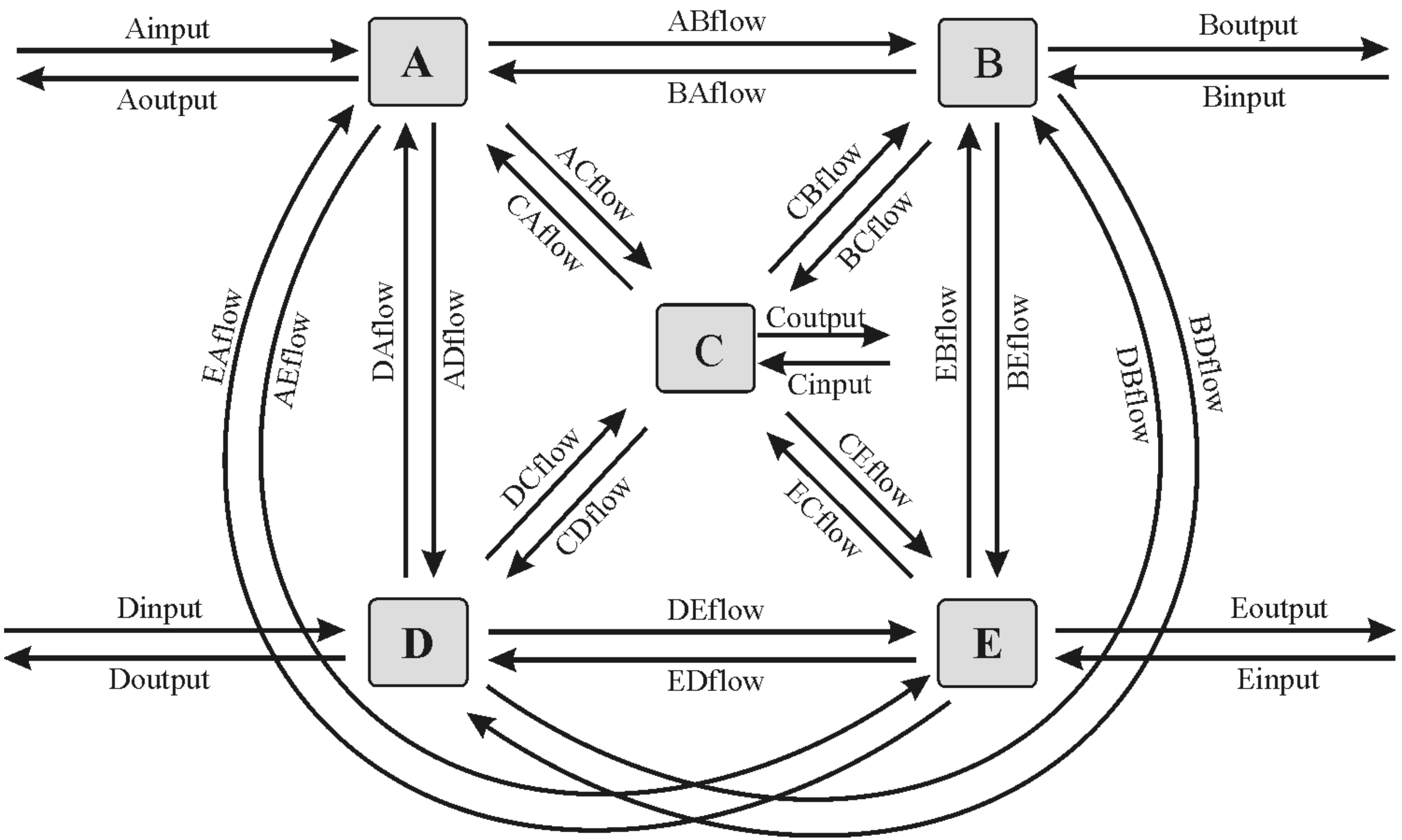


Systems with internal circuits or Competing pathways



Energy flow specificity ABC Onsager
n
mct
A input
A output
AB flow
BA flow
B output
B input
AC flow
CA flow
CB flow
BC flow
C output
C input
The Onsager network
A
B
C
E loss AB flow
Abh
kAB
Aoutput
A ABint flow
ABint
ABint B flow
Binput
Ainput
BAint
BAint A flow
B BA int flow
Boutput
kBA
kAC
CAint A flow
E gain BA fllow
BAh
kBC
CBint B flow
A ACint flow
B BCint flow
BCh
CAh
kCA
CAint
C CAint flow
BCint C flow
BCint
E gain CA flow
E loss BC flow
ACint
ACint C flow
C CBint flow
CBint
Cinput
Coutput
kCB
E loss AC flow
ACh
E gain CB flow
CBh

The "*Open5*" Abstract Chemical Network



The "*Open5*" model allows analyzing:
Efcontribution, Adding numerous catalysts, Feed back regulation, Competing pathways, Internal cycles

Composition and Organization Parameters in Abstract Networks

Composition-related parameters (Diversity)

Total number of parts

Number or part types

Partition of abundance

Organization-related parameters (*Org*) is arrangement in space or time;

Behavior is arrangement in time.

Org has two (ideally orthogonal) aspects (both can be expressed in energy and information units).

Order - Relative departure from the random state.

Complexity - The intricacy of the arrangement.

***Order* (*Ord*)**

Diversity-independent

Its information capacity is little size-dependent

***Complexity* (*Clx*)**

Diversity-dependent

Most differences between *Ord* and *Clx* are seen at the information level.

Hyp. Evolution toward higher organization is controlled by both DEflux and the capacity of the system to store information.

Confusion is often made between Total complexity and Ordered complexity.

tClx complexity is a property of the entire system.

oClx is a property of the non-random part of the system

Ordered Complexity

Order measures how unambiguously the system is organized.
oClx measures the intricacy of this organization.

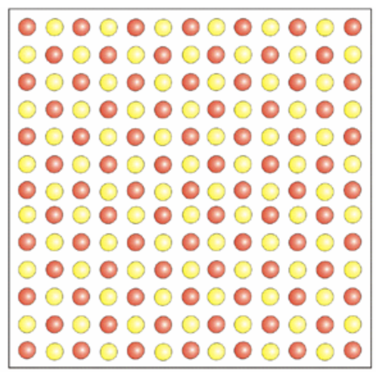
The random state has zero *Clx*.
Thermodynamic expectation has zero *Clx*.

Order is the departure of the system from randomness.
oClx is the departure of the ordered part of the system from sameness.

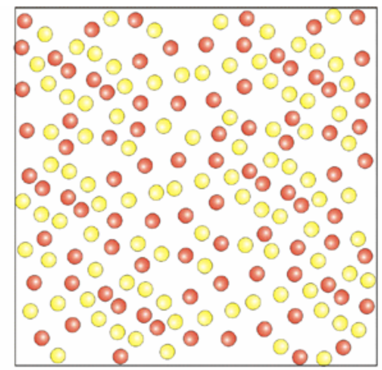
Yet, *Clx* is not identical with diversity - *Clx* decreases when the partition of abundance becomes more homogeneous, while Diversity increases.
Complexity is diversity at all levels – it includes partition of abundance as well.

Order vs. Complexity

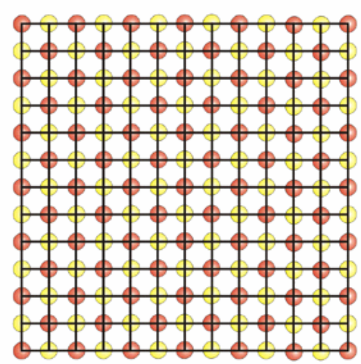
Org = *f*(Ord,Clx)



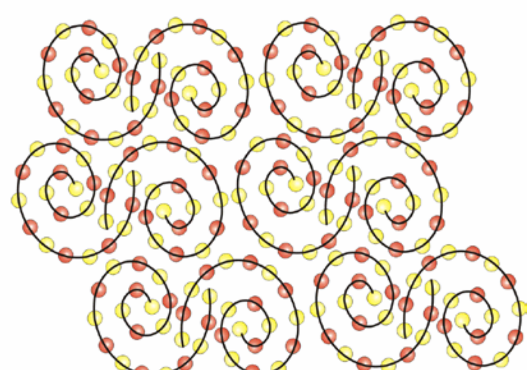
The surface of a periodic crystal shows highly repetitive organization



The surface of an aperiodic structure may appear random at certain scales



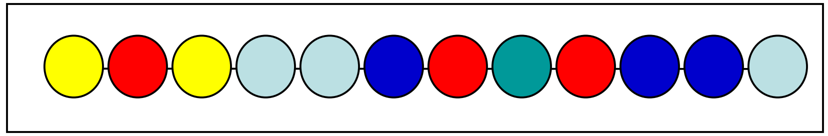
The surface patern of a periodic crystal



The surface pattern of an aperiodic structure

Measuring the Complexity of Energy Flow

Complexity as the intricacy of organization – the size of the smallest algorithm needed to describe the system. (it is not connected with energy)



(1) Kolmogorov complexity

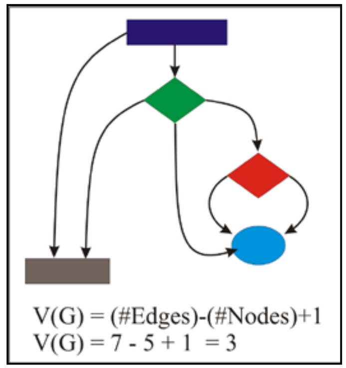
The I_C of a source line of code

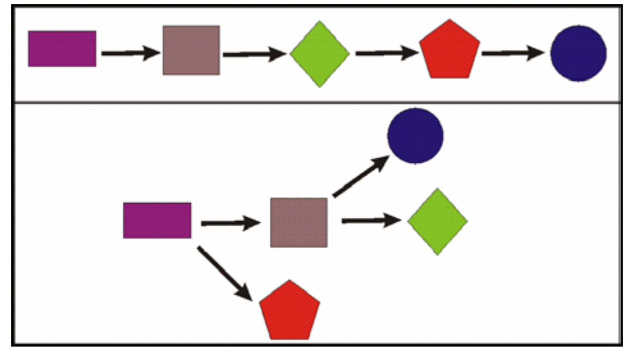
Shannon entropy ($I_{max} = N \log_2 M$)

(2) Cyclomatic complexity

(McCabe, 1976)

V(G) = (#Edges) – (#Nodes) + 1





(3) Measuring the *oClx* of an energy flow network.

Overall diversity of the organized part of a system.

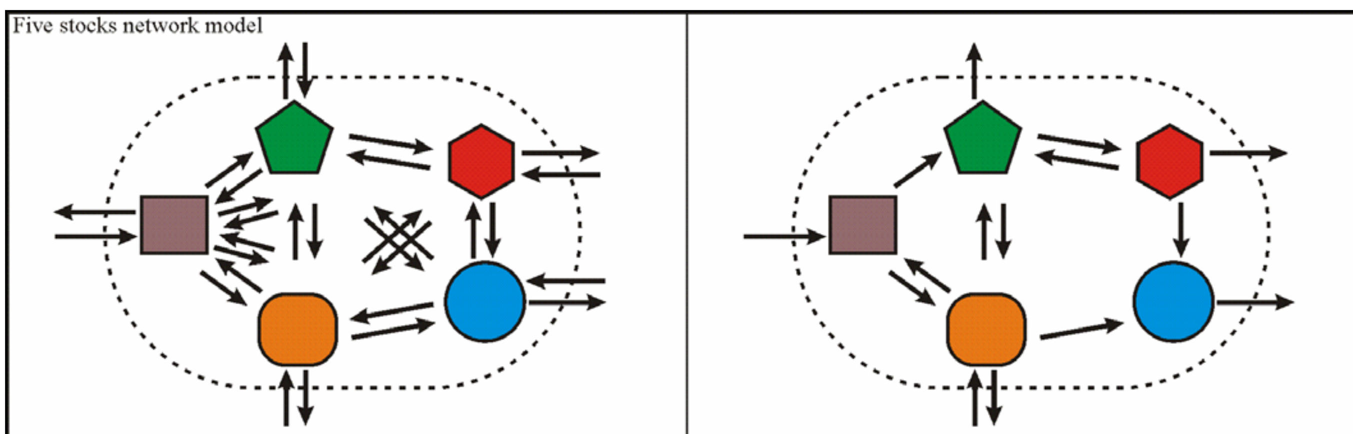
Complexity cannot range from 0 to 1.

It should not include stochasticity – because choices belong with the random part of the system.

Has to include any type of diversity (types of components and unevenness of abundance)

$Clx \sim f(Ord, Div)$

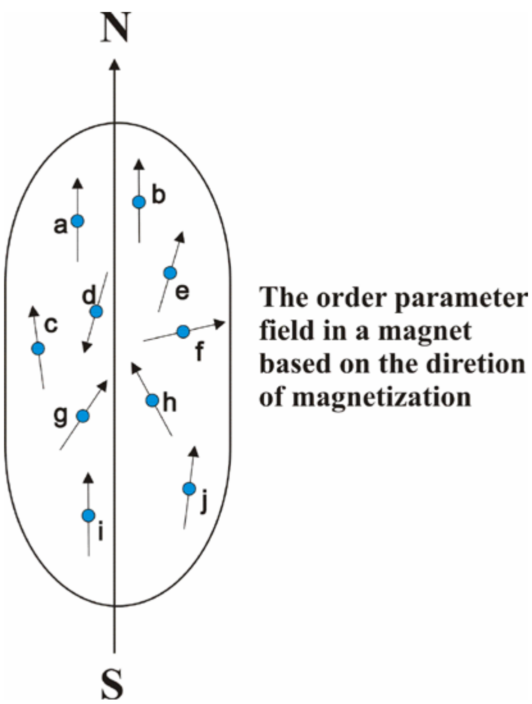
$Clx = n \bullet Het$



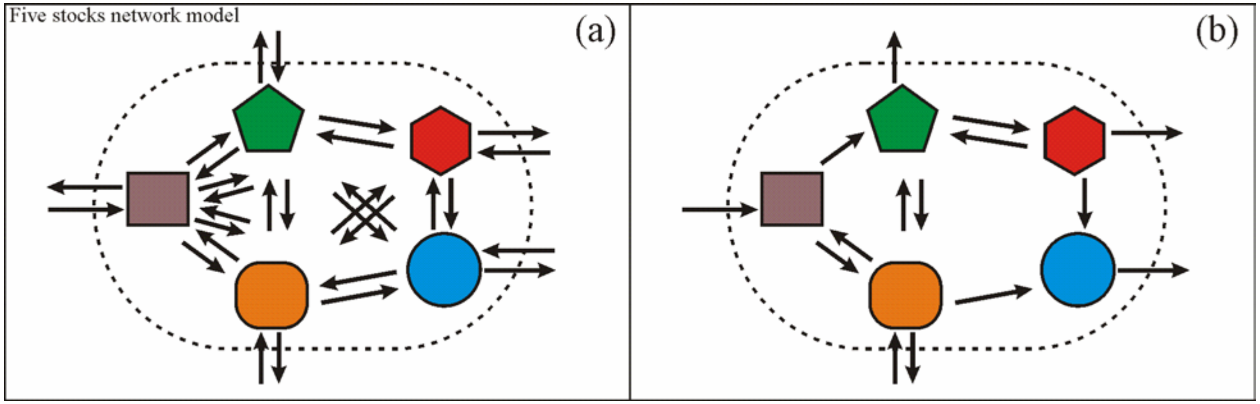
Measuring Order

Order parameter (Anderson, 1997)

$$S = \langle P_2(\cos\theta) \rangle = \left\langle \frac{3\cos^2\theta - 1}{2} \right\rangle$$



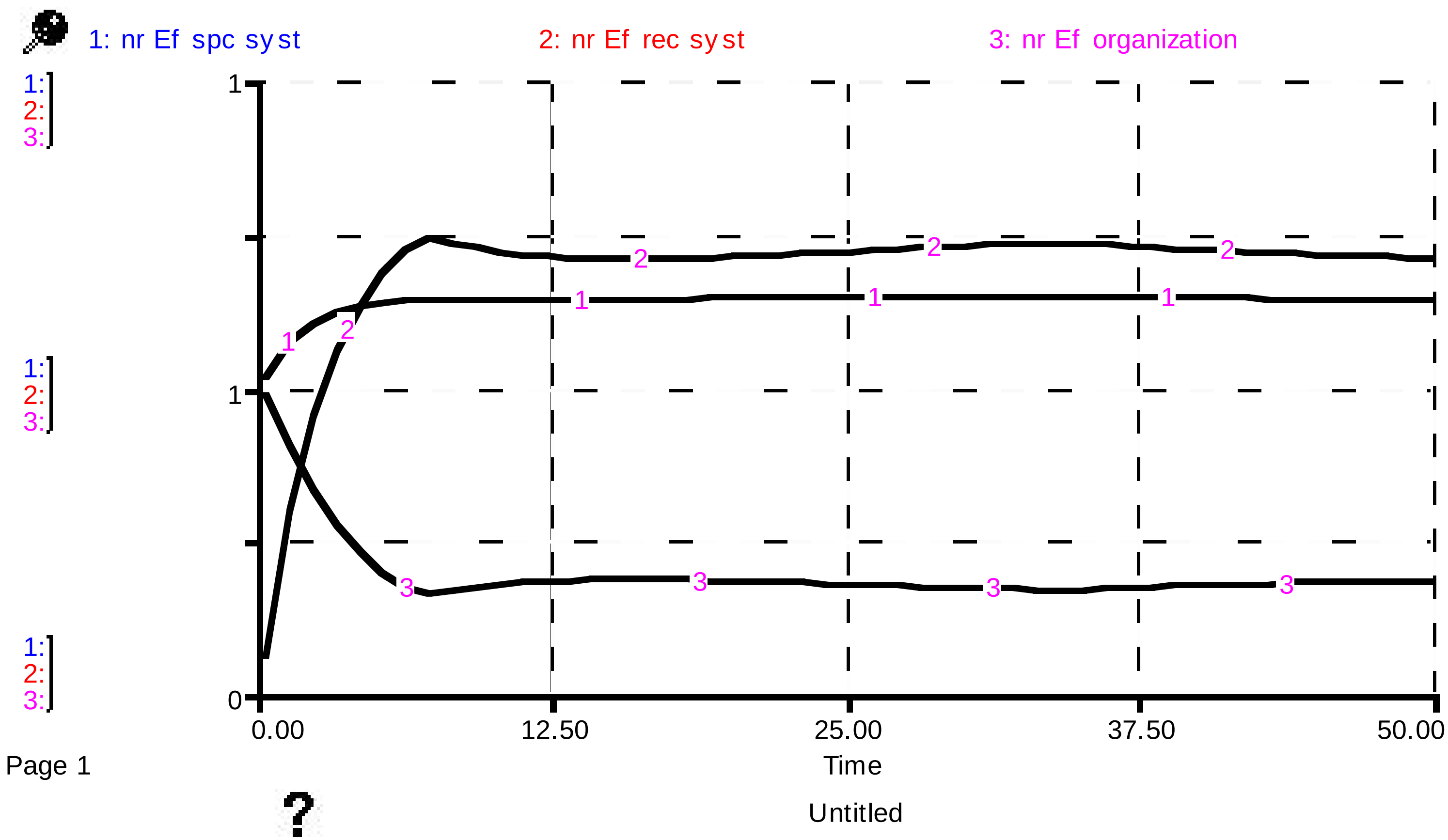
Order parameter in abstract networks.



$$O_{rd} = \sum_{i=1}^{n} \left(\frac{\left| \frac{E_f i(b)}{{}_t E_f(b)} - \frac{E_f i(a)}{{}_t E_f(a)} \right|}{\left(1 - \frac{E_f i(a)}{{}_t E_f(a)}\right)/2} \right)$$

Parameters of Energy Flow Budget and Energy Flow Oganization

Energy flow disequilibrium (${}_tE_f^{deq}$) = balance btw. inputs and outputs of the system.
Energy flow reciprocity (E_f^{rec}; $E_f^{rec}syst$) = the asymmetry of energy exchange between stocks (0-1).
Energy flow specificity (E_f^{spc}; $E_f^{spc}syst$) = non-randomness of energy exchange among stocks (0-1).



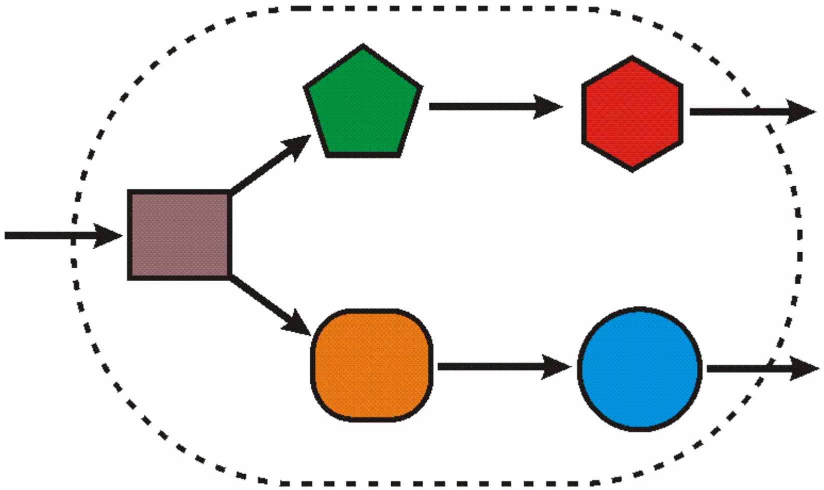
Catalysis- and Feedback-driven Organization

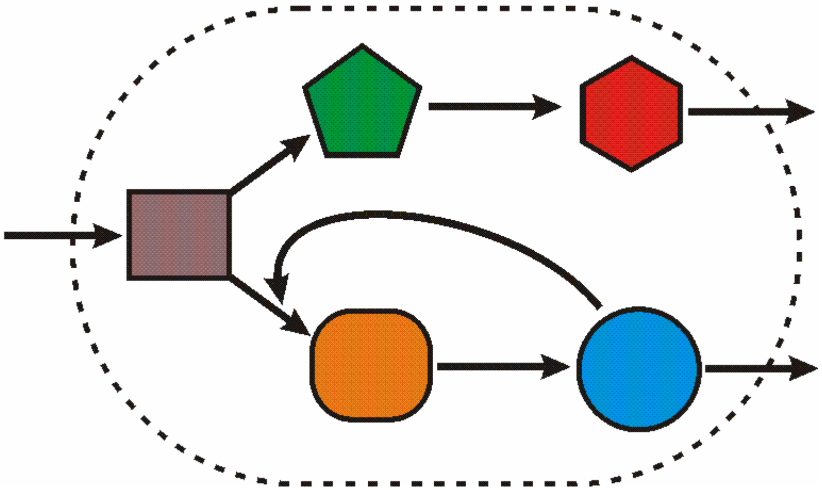
Simple five-stocks network with two competing energy flow pathways.

Order is controlled by initial disequilibrium and energy flow.

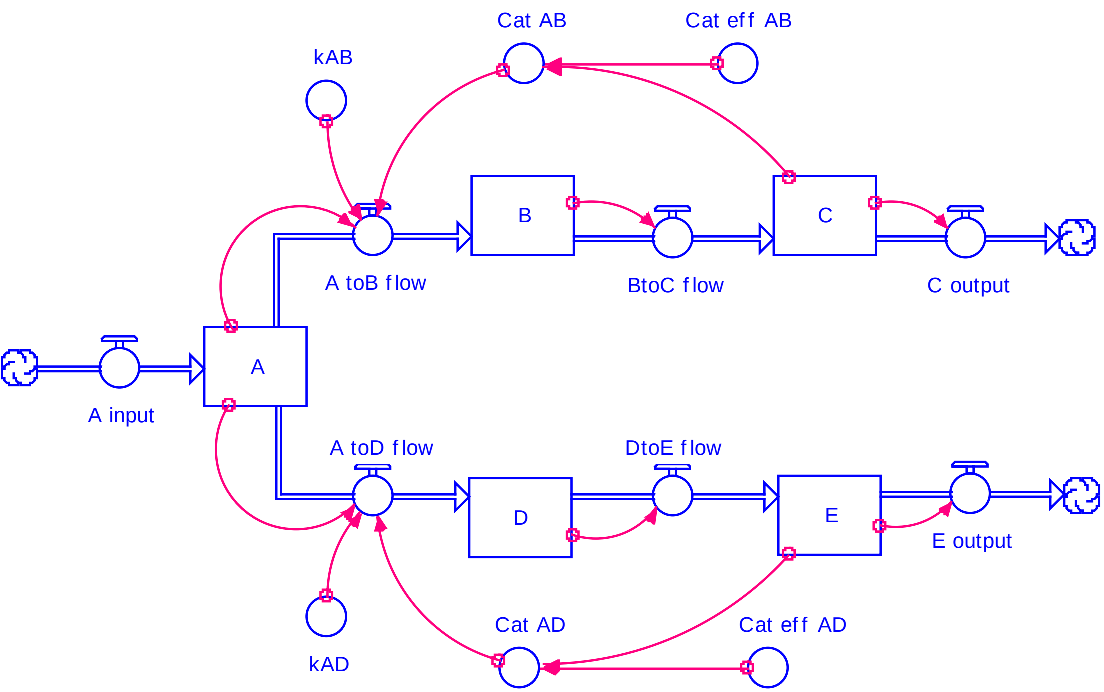
Hyp.1. The magnitude of the initial Deq is the main controller of changes in Order. Differences in catalytic efficiency will favor one pathway and affect organization through changes in order.
Hyp.2. The magnitude of the Ef is the main controller of changes in Ord.

Cat five stocks network model (file name: Cat five stocks network)



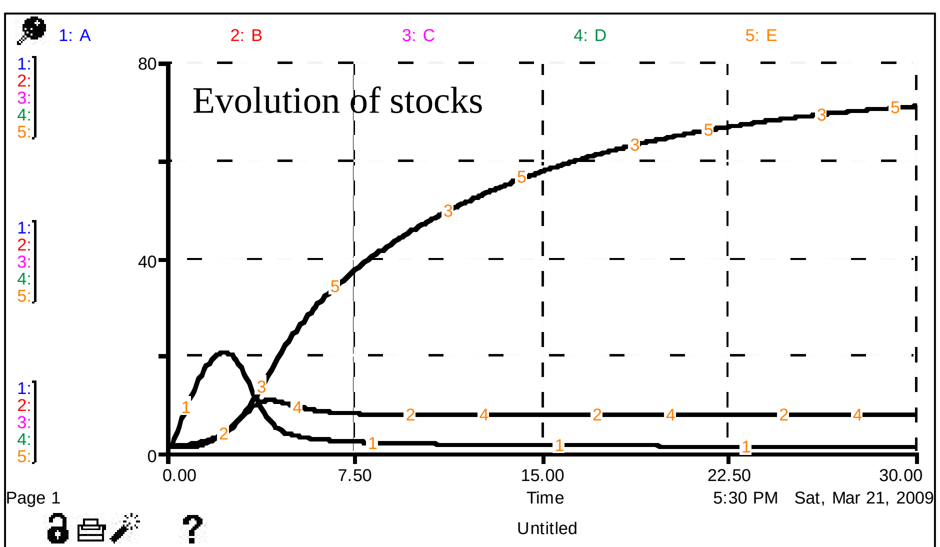


Catalysis-driven Organization

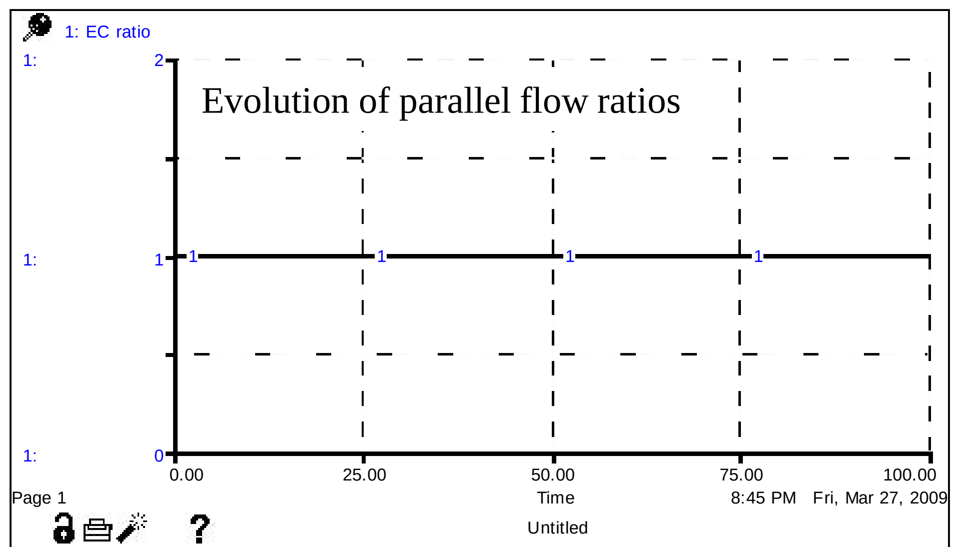


Cat eff AB = Cat eff AD
E/C = ct.

Downhill asymmetry caused by directional asymmetry.

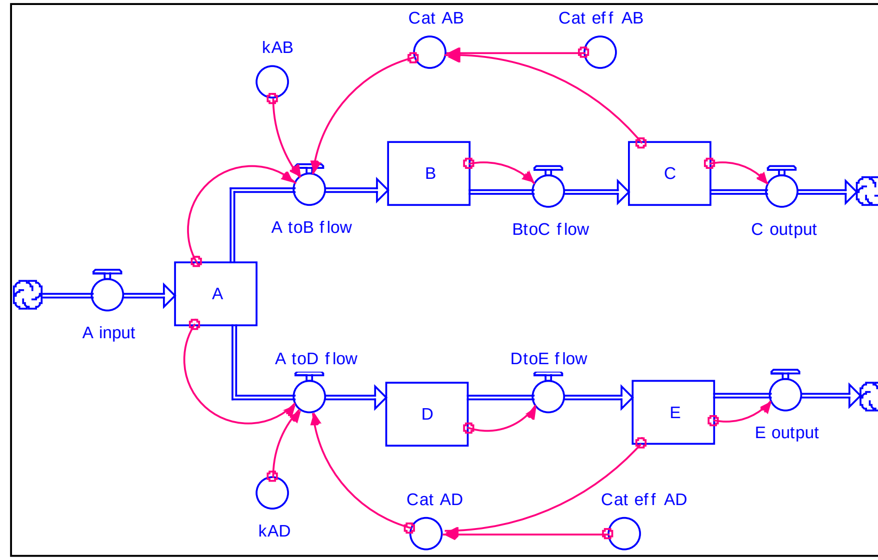


No bias can be created in symmetrical systems.

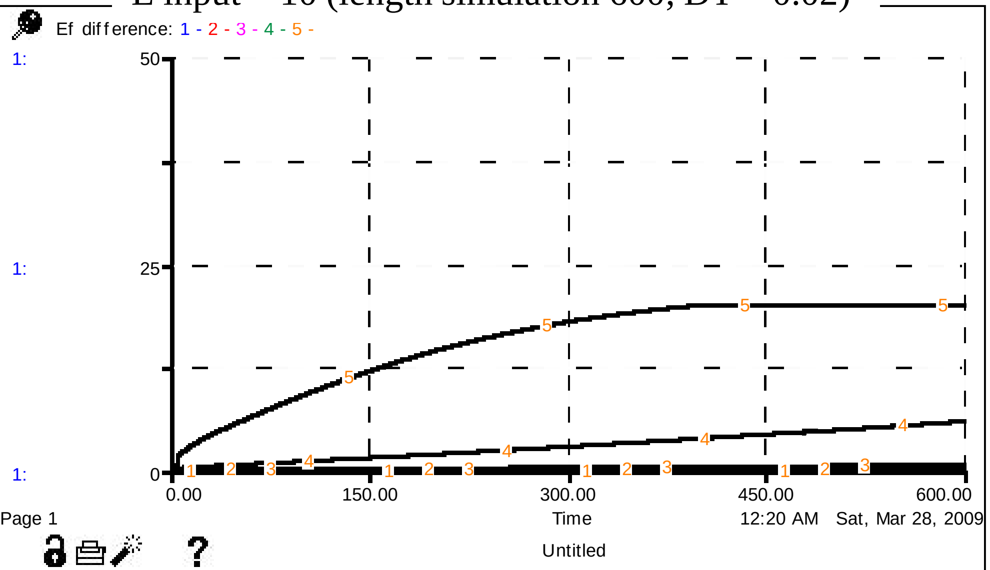


Parallel asymmetry and ΔEf producing Ef disequilibrium.

Cat eff	Run 1	Run 2	Run 3	Run 4	Run 5
AD/AB	1	1.0001	1.001	1.01	1.1

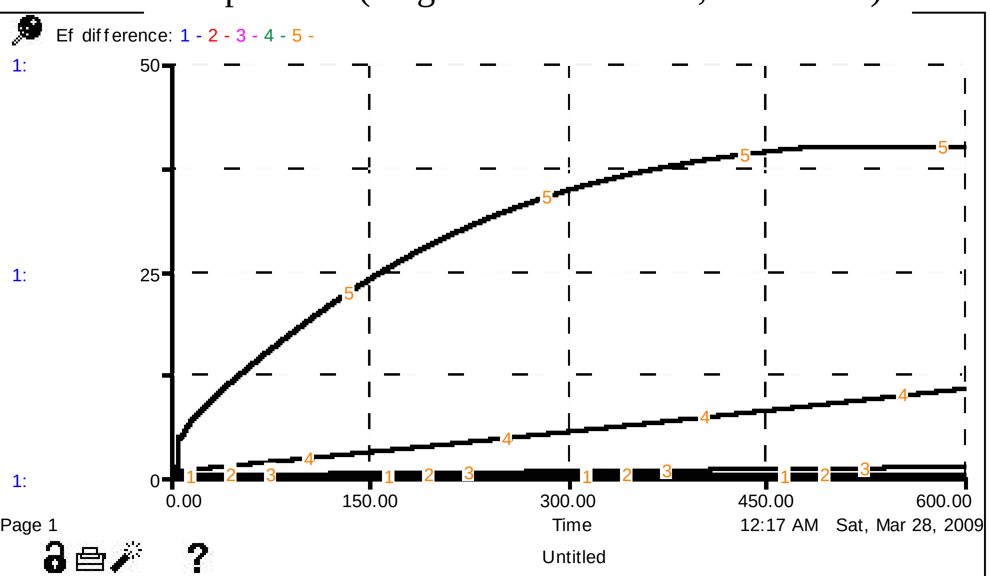


E input = 10 (length simulation 600; DT = 0.02)



Both initial asymmetry (^{+}Ord) and ΔE_f are needed to increase disequilibrium (Deq = Ef difference).
Deq ~ [Cat eff] • [Ef]

E input = 50 (length simulation 600; DT = 0.02)



Without internal disequilibrium there is no amplification of asymmetry.

The smaller the catalytic asymmetry the longer the time to reach steady [*Deq*].

AD/AB only probes local differences.

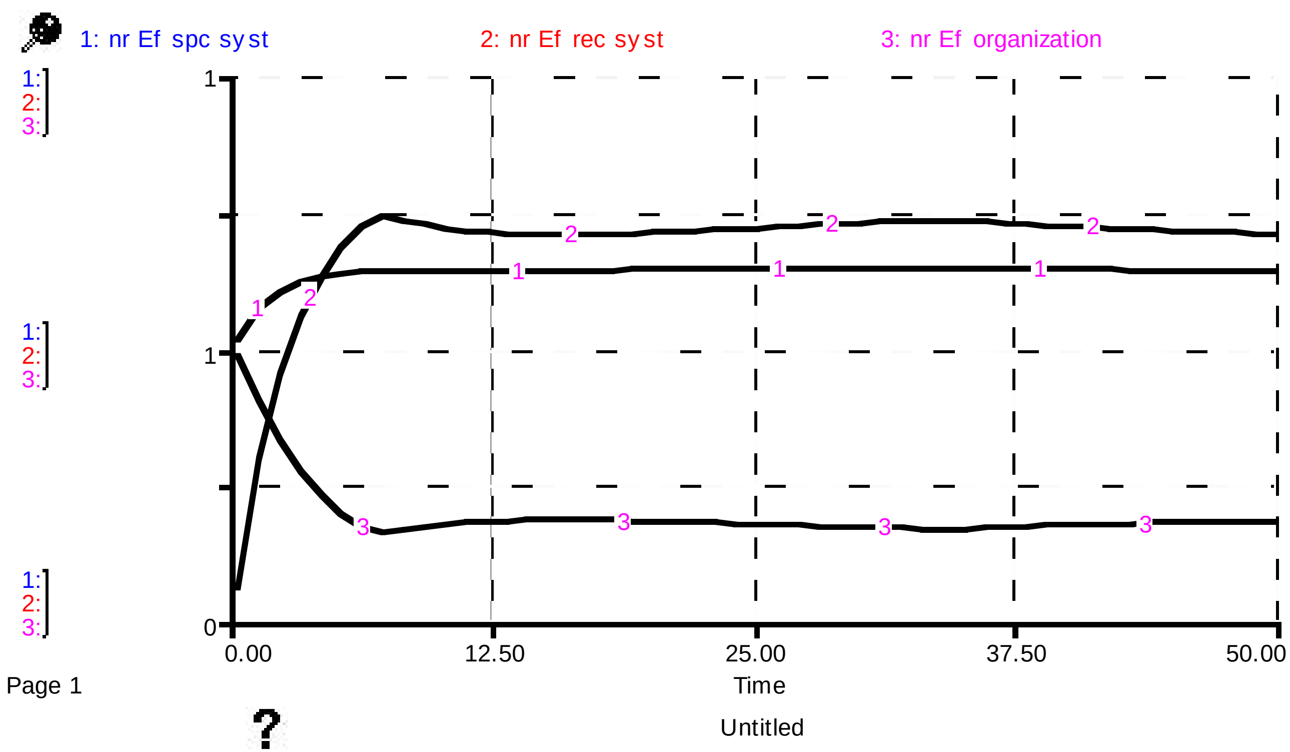
Parameters of Energy Flow Budget and Energy Flow Order

The Energy flow order or the Organization of the energy flow (E_f^{ord}) is the order associated with the energy flow. This parameter is also called energy flow directionality and is a combination of two factors: Low reciprocity (E_f^{rec}) and High specificity (E_f^{spc}). Because both these factors were calculated in the range 0 to 1, E_f^{ord} is proportional with:

$$E_f^{ord} \sim E_f^{spc} \bullet (1 - E_f^{rec})$$

0 = diffuse flow with no specific direction, lack or organization,

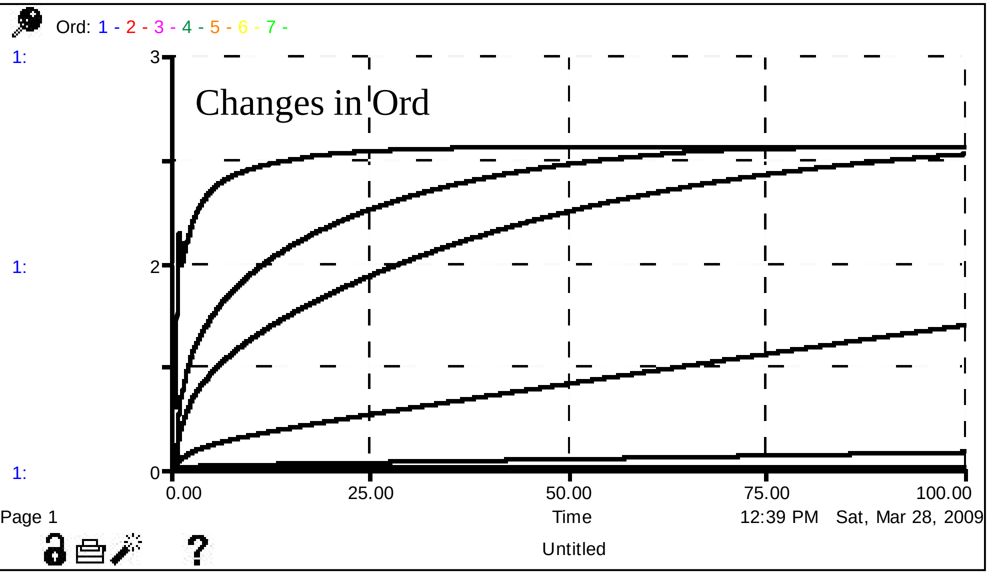
1 = high organization with very specialized connections, non-random (unambiguous) distribution of E.



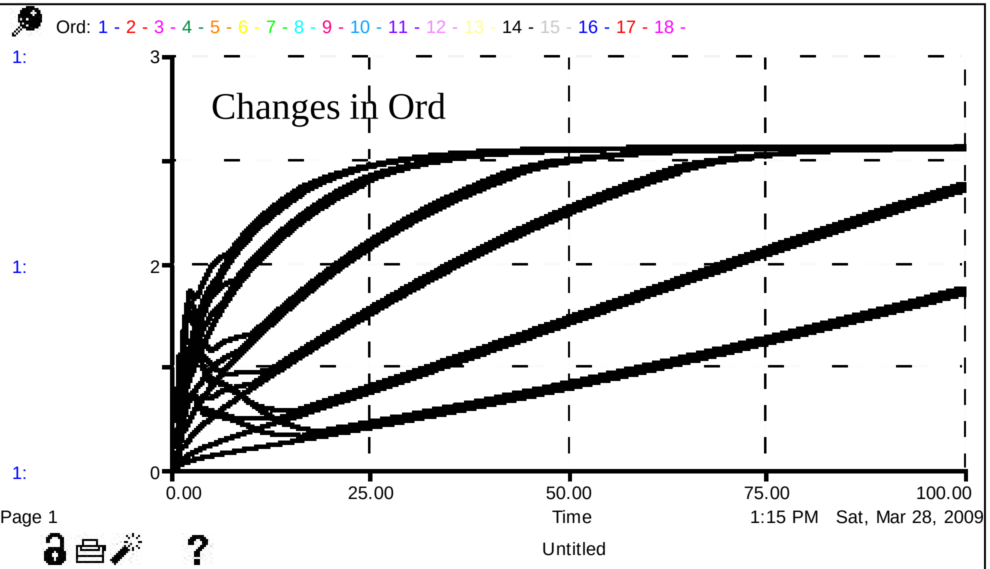
Changes in Order

Ord measures changes in the overall *Ef* path preferences relative to the initial state.

The effect of internal asymmetry on *Ord*. (Ainput=10; Duration=100; DT=0.01; Cat eff AD/AB=1;1.001;1.01;1.1;1.5;2; 10).



The effect of *Ef* and *Deq* on *Ord*. (Cat eff AD/AB = 1.1; 1.2; 1.5; 2; 4; 8; Duration 100; DT = 0.005; Ainput = 2; 4; 8).

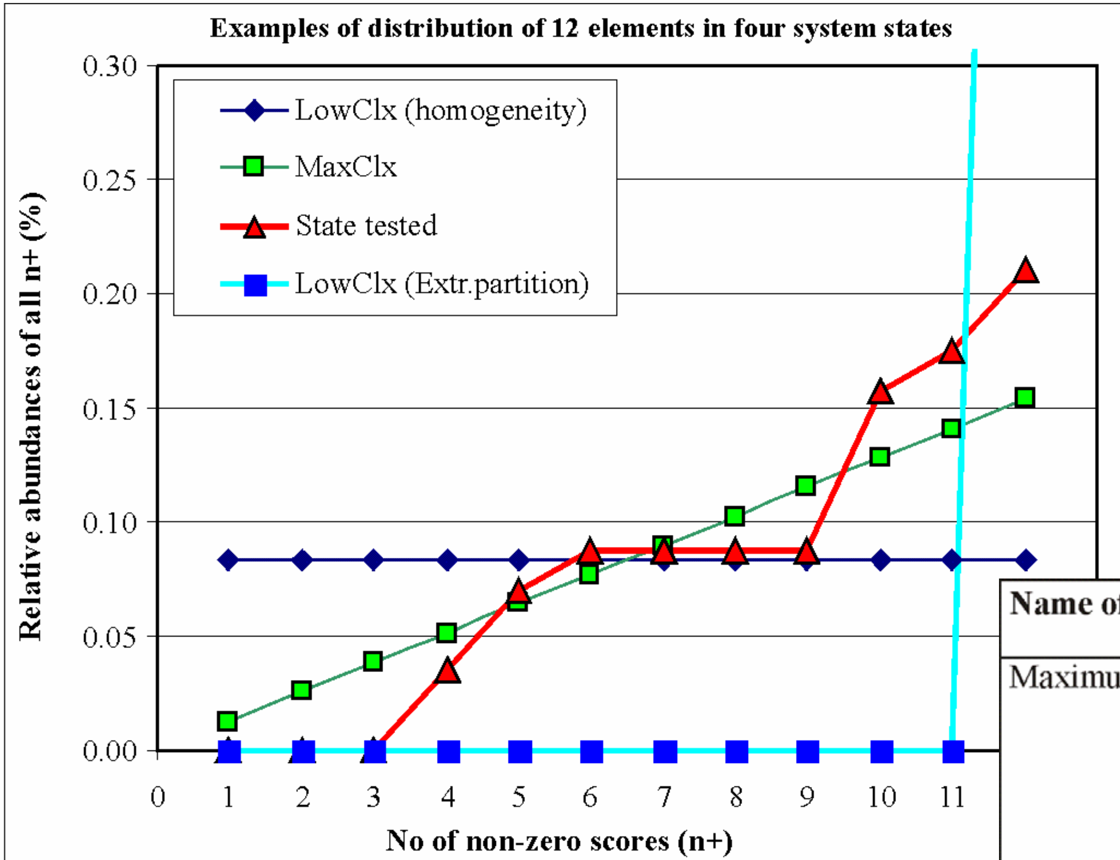


***Deq* is the main controller of Δ*Ord*.**
***Ef* is not the means to amplify the *Deq*.**

Small networks have a *p* = 0.5 to be asymmetric.

A connection exists between Eflow, System size and Phase transitions toward organization.
1 ul = 3.3 • 10^{19} water molecules.

Maximum Partition Complexity

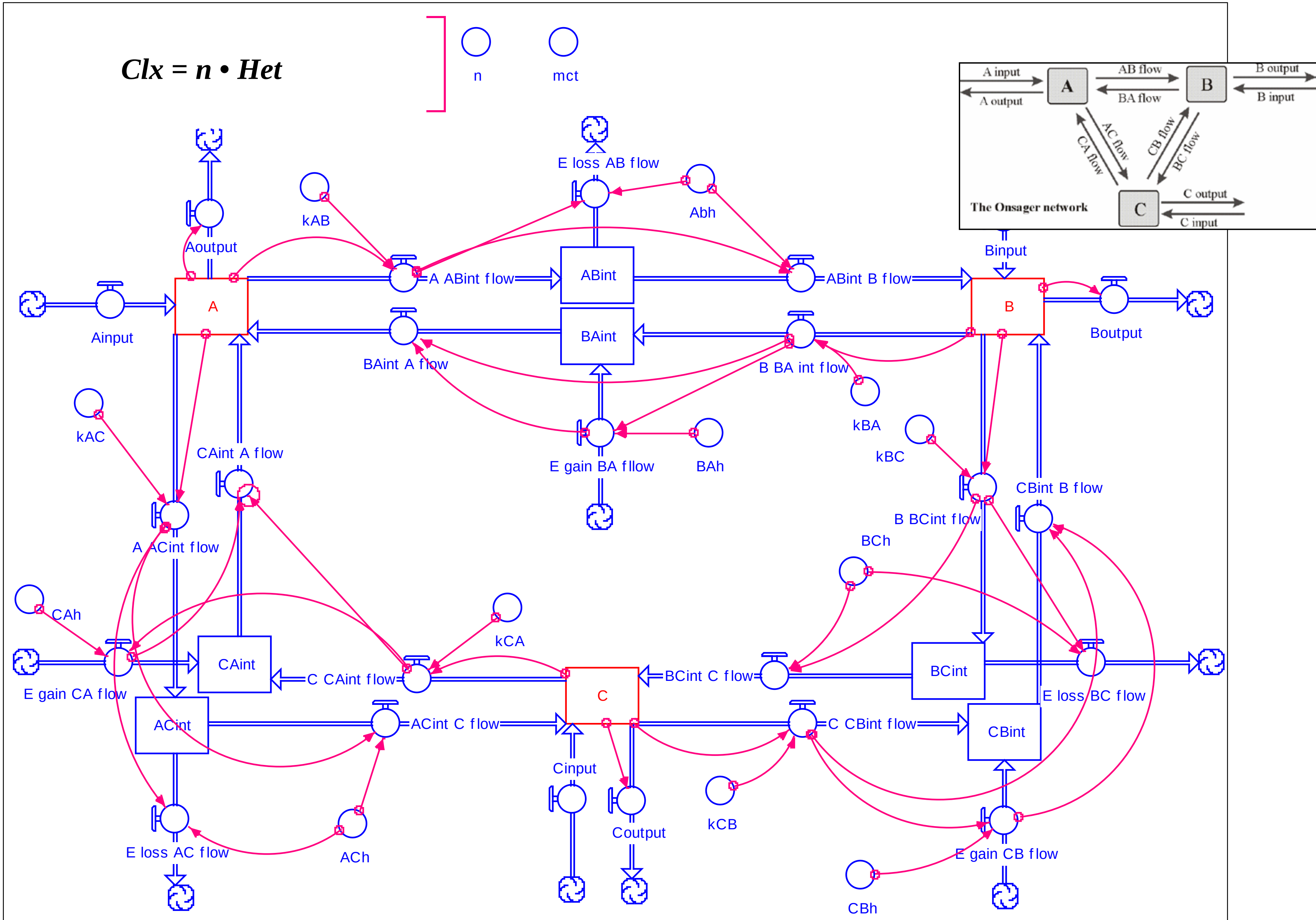


Name of the state	Notation for abundances	Distances
Maximum Complexity State	m%	
State to be tested	m'%	m%-m'%
Extreme partition state	m"%	m%-m"%

The heterogeneity of abundance distribution (Het) = Similarity with the "Maximum Complexity state", or the departure from the lowest complexity of a distribution of elements.

Measuring Complexity in a Network

$$Clx = n \bullet Het$$



Summary

- The system's state is controlled by the E_{flux}, while the evolution of the system toward lower entropy (more organization) is controlled by $+\Delta E_{flux}$.
- The OEL is not about increasing *Order* or *Complexity*; it is about searching for the *Organization* that will maximize and normalize the production and dissipation of heat.
- The "*Physical purpose of life*" is to dissipate energy gradients in both time and space.
- Irrespective of the E_f, no asymmetry means no evolution toward Organization.
- Small systems are 50% asymmetric, and thus *Ef* through competitive pathways will be asymmetric. As systems increase in size this can be compensated with using catalysis or non-linear amplification.
- Whether the state of lower entropy is gained via increasing Order or Complexity depends on: diversity, pre-existing order and the information costs of complexity.
- The simplest means to limit the information costs of Complexity from skyrocketing is to decrease the internal diversity.

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